

Article

Conservation Requirements of European Eel (*Anquilla anquilla*) in a Balkan Catchment

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Abstract: The European eel (*Anquilla anquilla*) has been declining throughout its area of distribution, is addressed in several pieces of legislation, and is the target of extensive restoration efforts. Therefore, investigating and conserving natural eel habitats is urgently needed. Large, near-natural rivers have become rare in Europe but the Balkans host some of the extant examples. However, several Balkan rivers—among them the transboundary river Vjosa/Aoos of Albania and Greece—are under threat from planned hydropower constructions. This study synthesizes European eel catch data from four institutions and the results of a recent electrofishing survey. Population density and structure as well as habitat choice were studied at different spatial scales. We calculated densities for each meso-habitat (0–1303 ind./ha) and extrapolated these values across three different hydromorphological channel sections (meandering: 70 ind./ha, braided: 131 ind./ha, constrained: 334 ind./ha), resulting in an overall mean density of 168 ind./ha. Proposed hydropower plants would cut off about 80% of the catchment currently accessible and impact river sections downstream of the dams by disturbing hydrological dynamics. By linking study results to relevant legislation and literature we provide evidence-based data for water management decisions. We call for the Vjosa/Aoos to be protected in order to secure its outstanding conservation value.

Keywords: braided river; catadromy; habitat choice; hydropower; legislation; density; yellow eel; Vjosa

1. Introduction

European eels (*Anguilla anquilla* Linnaeus 1758) exhibit a highly unique catadromous life history cycle. Following their reproduction in the Sargasso Sea (Western Atlantic Ocean), a portion of the larvae (leptocephali) arrive in the Mediterranean Sea on the Continental Shelf after 2–3 years of oceanic migration, covering a distance between 5000 and 10,000 km [1–3]. After metamorphosis, the yellow eels then migrate upstream into rivers wherein they mature for 3 (males) to 20 (females) years. After a second metamorphosis into a sexually mature stage (silver eels), the eels then migrate downstream and migrate back to their reproductive grounds in the Sargasso Sea [2]. Despite their broad distribution from subarctic environments in the Kola Peninsula and North Cape in northern Europe to subtropical

environments in Morocco and the Mediterranean regions of Egypt, they are considered to be one panmictic population, an hypothesis supported by genetic analysis [4,5].

The European eel population has been declining since the 1980s throughout its area of distribution. Several hypotheses have been suggested for this decline, suggesting problems occurring either during the continental or the oceanic part of the life cycle. Marine causes such as shifts in the Gulf Stream are thought to impact the survival of leptocephali larvae during their transoceanic migration, but inland causes such as overfishing, obstructions to upstream and downstream migration, loss of habitat, water quality, and parasite and xenobiotic contamination are documented, which collectively have reduced the quality and quantity of spawners leaving the inland waters of Europe reviewed by [6–9]. Migration barriers are considered as a major threat to the European eel population, similarly as for other anguillid species [10]. Several studies have reported large-scale extinctions of inland stocks from rivers upstream of dams [11,12]. The European Inland Fisheries Advisory Commission (EIFAC) and the International Council for the Exploration of the Sea (ICES) estimated that this noticeable and prolonged decline has left only 10% of the historical European eel population intact [13].

Several legislative documents and conservation directives have targeted the protection of European eel, and the species has been listed as critically endangered on the International Union for Conservation of Nature (IUCN) Red List of threatened species [10]. The critical levels reached by the eel population in Europe resulted in Regulation EC 1100/2007 [14], which requires member states to reduce anthropogenic mortalities, thereby permitting the movement of at least 40% of the silver eel biomass to the sea as compared to the best estimate of eel movement, if no anthropogenic influences impacted its migration.

Currently, the Mediterranean coastal habitat still constitutes a considerable proportion of the overall continental habitat of the European eel [15]. It has been suggested that the eels that reach the Mediterranean basin from Southern European and North African countries contribute significantly to the total global eel population [16]. However, Aalto et al. [17] also found a region-wide decline in the eel catch that began in the mid-1970s, caused by the above-mentioned reasons. Large natural (and passable) rivers have become rare in Europe, a fact reflected in the high conservation status of many riverine ecosystems. While the Balkan Peninsula still harbors several intact river corridors, most of these are under threat from planned hydropower exploitation [18]. Unfortunately, little information is available on the biota under threat [19]. The European eel occurs in all river drainages reaching the Albanian Adriatic and the Ionian seas, although the population densities in these systems have decreased dramatically over the last few decades [20,21].

The river Vjosa in Southern Albania has been identified as one of the few remaining reference sites for dynamic floodplain rivers in Europe, but has recently become threatened due to the concession of new hydropower plants (HPP) in its lower reaches. Evidence-based studies on the conservation value of such systems are prerequisite for an assessment of the ecological effects caused by hydropower development and are therefore indispensable [19,22]. Thus, the high abundance of European eels caught as part of joint research carried out by teams from Albania, Austria, and Germany in 2017 [23] attracted significant attention [24,25]. The data that is currently available detailing the river habitats of the European eel in the whole Mediterranean region is scarce, rough, and unreliable, and further research is therefore urgently needed [17].

The aim of the present study is to (a) synthesize different data sources detailing the presence of European eels in the Vjosa/Aoos catchment, (b) describe the spatial organization and habitat use of European eel within the river system, and (c) discuss the conservation value of this river and potential legal conflicts of hydropower development in the Balkans with regard to the European eel.

2. Materials and Methods

2.1. Study Site

The river Vjosa flows over a distance of 272 km, from the Pindos Mountains (at 1343 m.a.s.l.) east of Ioannina in Greece to southern Albania where it finally reaches the Adriatic Sea. The first 80 km of this river are in Greece, where the river is named Aaos (Figure 1).

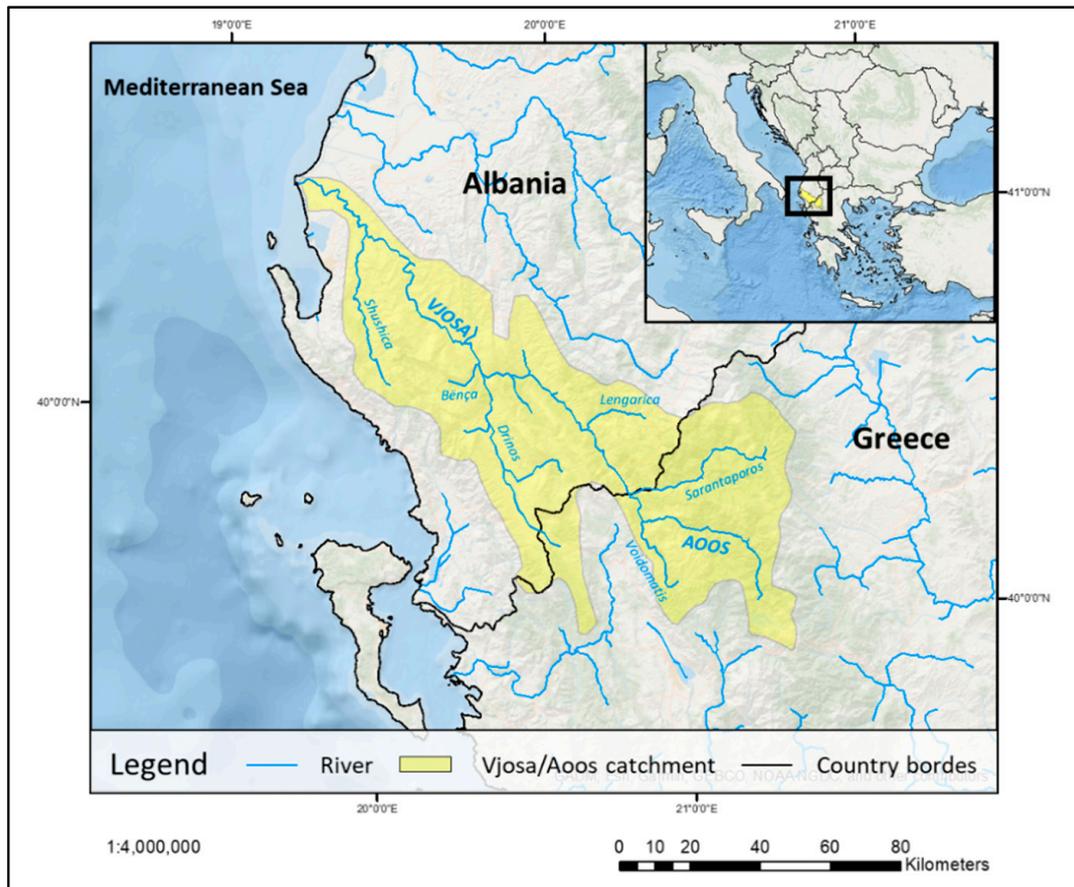


Figure 1. Catchment of river Vjosa/Aaos and its main tributaries. The map is based on Aguilar-Manjarrez [26] and Lehner et al. [27].

The entire catchment covers 6704 km², with various channel types occurring along its course such as gorges in the upper parts, braiding and branching sections (Figure 2) in the middle and lower courses, and meandering stretches close to the river mouth. The climate of the lower catchment is Mediterranean, changing upstream into sub-Mediterranean, temperate, and finally alpine climates with a pluvio-nival hydrological regime [19]. A detailed description of the Vjosa and its accompanying landscapes is available in Schiemer, Drescher, Hauer and Schwarz [23]. Including all perennial tributaries, the entire river network encompasses approximately 1109 km, of which 1060 km are currently accessible to migratory European eels.



Figure 2. Vjosa at Pocem. Reproduced from © Gregor Subic permission (2017).

2.2. Eel Sampling, Data Acquisition, and Analysis

The main fish sampling campaign was conducted from 23 May 2018 to 26 May 2018 using the strip-fishing method. This method is designed for sampling and roughly estimating fish stock density in medium-sized rivers such as the Vjosa. The concept is to quantify stocks by fishing a considerable number of distinct, habitat-specific ‘strips’ (1.5 m width) with electrofishing-boats (EF) and extrapolate the catch data from these samples to the whole river section according to a standardized procedure [28]. Stunned fish are caught using dip nets. If not all the stunned fish are caught by the dip nets, especially when fish abundance is high, a catching efficiency is visually estimated (0–100%) for the respective strip and used for stock calculations. The fish were identified, measured, and released back to the river after sampling of a strip was completed. Sampling was performed from Tepelene downstream to the river mouth (Figure 3B) in all three morphological river sections (meandering, braided, and constrained).

Total water surface area per river section (meandering, braided, and constrained) was measured from satellite images using Argis. Within these sections, nine representative segments (each 15 ha) were analyzed for their meso-habitat distribution. The following meso-habitat types were considered: main arm (deeper sections situated in the middle of the river, not influenced by the shoreline or any other riparian features), riffles (shallow river sections with turbulent flow), sand banks (bank areas characterized by sandy substrate and slow flow velocities), gravel banks (instream or bank features consisting mainly of gravel), sidearm flow (secondary channel connected to the river on both sides with unidirectional current), sidearm standing (river channel connected only on one side, standing water), cut banks (outside bank of a water channel, normally deeper and high flow velocities), tributaries (within the active channel and flowing into the Vjosa), groins, vegetated- and rock shore.

European eel abundances (ind./ha), standard deviation and confidence intervals ($\alpha = 0.1$) were calculated for each type of meso-habitat. The total stock for the three morphological river sections was then computed by considering the areal share of each meso-habitat type in the respective section compare [28]. As we cannot account for inherent biases of electrofishing, for example the expected lower efficiency in deeper water, these overall stock estimates should be considered rough, and if anything, underestimated of the actual stock size throughout the river.

In addition to our sampling we also compiled and synthesized European eel records from various databases (University of Natural Resources and Life Sciences, Austria; Hellenic Centre for Marine Research, Greece; Pindos Perivallontiki, Greece; Agricultural University of Tirana, Albania).

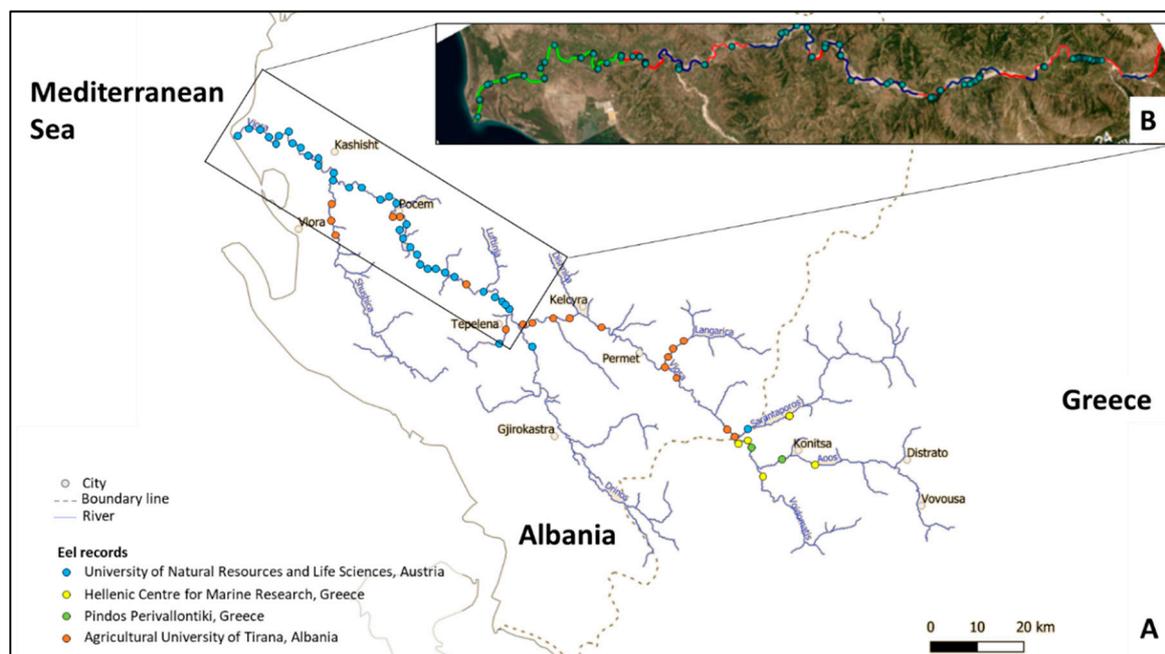


Figure 3. (A) Sites ($n = 71$) at which the European eel (*A. anguilla*) have been recorded in the Vjosa/Aoos catchment (from 2011 to 2019); (B) Lower stretch of the river with the location of the quantitative sampling points (from 2018, green points) and indicated river typology (green = meandering, red = constrained and blue = braided).

3. Results

During the four-day sampling campaign, 76 stretches were fished, with a total catch of 2878 fishes across 18 species [29]. In total, 143 individual European eels (Figure S1) were caught and measured. If estimated catch efficiency (i.e., eels visualized but not captured) is considered, 326 eels were recorded. The size of eels ranged from 85 to 510 mm total length (Figure 4) and were found in all three morphological river sections. Specimens smaller than 130 mm total length were mainly caught in constrained sections, and the three largest eels were found in the meandering sections.

Along the investigated river length of 110 km we measured 596 ha water surface area for the braided section, 348 ha for the constrained sections and 367 ha for the meandering section. Table 1 indicates the areal share of the available meso-habitats for each of these morphological river sections. The braided section gravel banks (33.2%), sidearm flowing (33.9%) and main arm (26.6%) dominate the meso-habitat distribution. Constrained sections exhibit high shares of main arm areas (65.3%) followed by gravel banks (20.2%) while in the meandering section the main arm (81.2%) is followed by vegetated shore (8.5%).

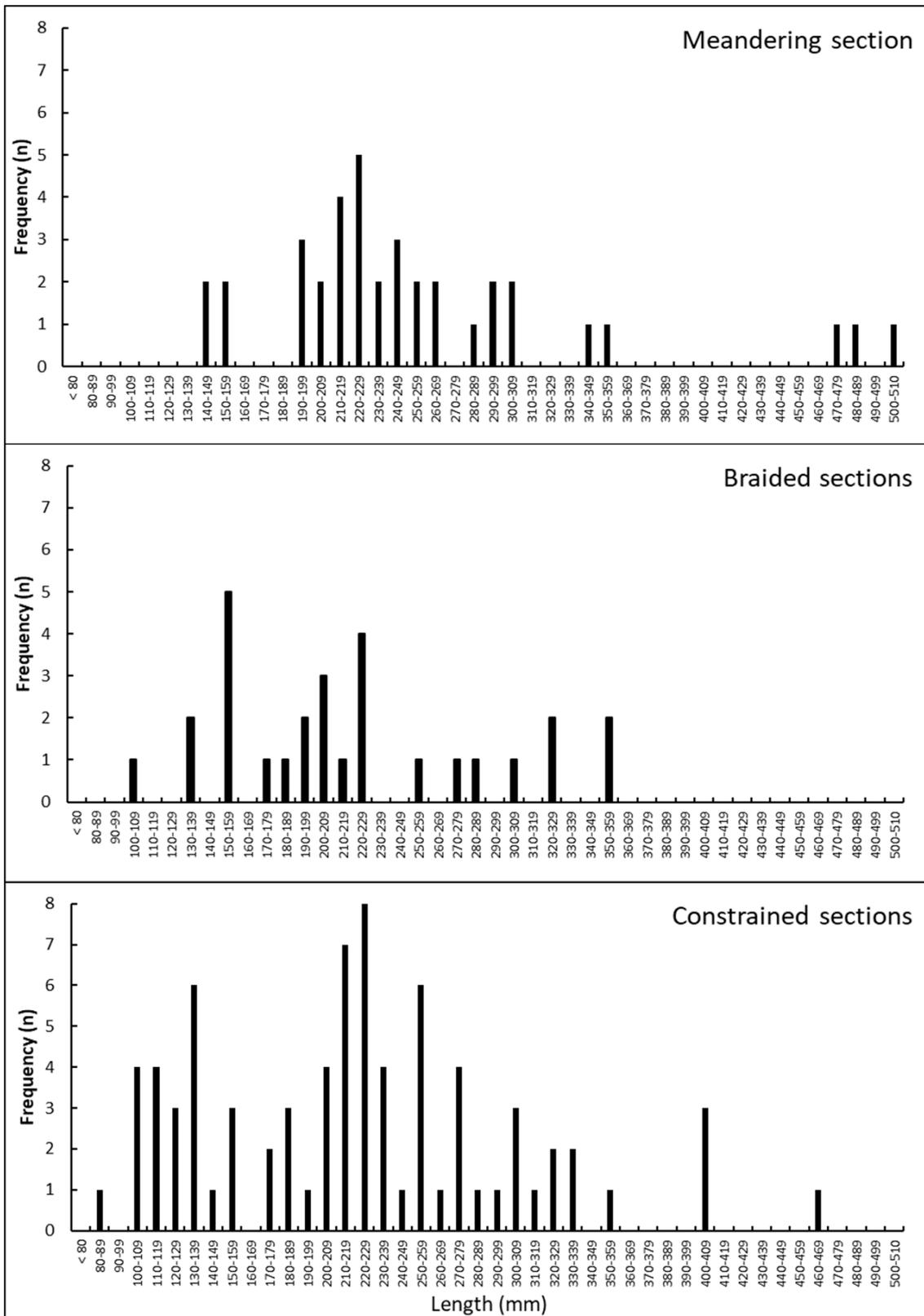


Figure 4. Length–frequency graph of the European eel (*A. anguilla*) (n = 143) with total number of individuals caught in each section in 2018.

Table 1. Meso-habitat distribution (in %) for all three morphological river sections and mean eel densities for each meso-habitat type in 2018.

Morphological River Section	Meso-Habitat	Areal Share of Meso-Habitats	No of Stretches	Total Fished Length	Mean ind./ha	Standard Deviation	Confidence Interval ($\alpha = 0.1$)
Braided	Main arm	25.58	3	160	0.0	0.0	0.0
	Cut bank	1.93	1	60	222.2	0.0	0.0
	Riffle	1.91	3	195	624.3	596.9	566.9
	Sand bank	1.36	3	175	74.1	104.8	99.5
	Gravel bank	33.16	8	505	332.9	295.0	171.6
	Sidearm flowing	33.91	2	100	0.0	0.0	0.0
	Sidearm standing	1.59	2	110	117.0	117.0	136.0
	Tributary	0.56	4	240	249.4	280.5	230.7
	<i>Total</i>	100	26	1545	202.5		
Constrained	Groyne	0.33	1	60	444.4	0.0	0.0
	Rock shore	2.32	3	230	133.0	113.6	107.9
	Main arm	65.3	4	200	0.0	0.0	0.0
	Cut bank	4.57	5	360	525.0	609.9	448.6
	Riffle	0.74	2	80	1010.1	1010.1	1174.8
	Sand bank	0.21	2	110	392.2	392.2	456.1
	Gravel bank	20.15	14	2109	1303.6	2522.0	1108.7
	Sidearm standing	2.3	1	20	1233.3	0.0	0.0
	Tributary	4.07	1	150	55.6	0.0	0.0
<i>Total</i>	100	33	3319	566.4			
Meandering	Groyne	2.11	3	200	777.8	742.6	705.2
	Main arm	81.18	3	150	0.0	0.0	0.0
	Cutbank	6.69	2	155	344.0	66.2	77.0
	Sand bank	1.56	5	370	380.5	346.3	254.8
	Vegetated shore	8.45	4	305	285.9	75.0	61.7
	<i>Total</i>	100	17	1180	357.6		

Additionally, the mean eel densities, (incl. standard deviation and confidence interval) calculated for each meso-habitat are given in Table 1, varying between 0 and 1303 individuals per ha.

The highest eel densities for meso-habitats were observed in the constrained section, in particular in gravel banks (1303 ind./ha), and standing sidearms (1233 ind./ha), whereas no eels were caught in the middle of the main arm in all three sections. In the braided sections, riffles (624 ind./ha) showed highest values, whereas in the meandering section densities peaked close to groins (778 ind./ha). Mean eel density was 202 ind./ha over all meso-habitats in the braided sections, 566 ind./ha in the constrained sections, and 358 ind./ha in the meandering sections. Overall, this depicts an average of 376 ind./ha.

However, a more realistic picture is gathered when the areal distribution of the available meso-habitats within the river stretches (Table 1) is considered. Mean catches are extrapolated according to the percentage share of meso-habitats, resulting in 131 ind./ha in the braided channel sections, 334 ind./ha in the constrained channel sections, and 70 ind./ha in the meandering channel section. For the investigated part of the river Vjosa (110 km river length or 1311 ha water surface) this adds up to an estimated total stock of 220,000 European eels or 168 ind./ha or 2000 ind./km.

The compiled database reveals 294 eels caught from 71 sites distributed throughout the entire Vjosa/Aoos river system during the last 10 years by various methods (Electrofishing, shore seine and dipnet). In the river Vjosa, eels were caught along a gradient of 220 km, up to an altitude of 500 m.a.s.l., with sizes ranging from 85 to 540 mm (Table S1). Additionally, in all investigated tributaries (Shushicë, Bënça, Drinos, Langarica, Sarantaporos and Voidomatis) the presence of eels has been documented. The majority were caught on Albanian territory while seven sites are located in Greece (Figure 3A).

4. Discussion

In contrast to most European rivers, a high number of Balkan rivers are still in an excellent hydromorphological state and are therefore recognized as biodiversity hotspots [18,30]. Many authors propose that historically the European eel could access all rivers along the Adriatic and Aegean coasts [10,31]. Important Balkan rivers for the European eel include the Neretva in Croatia and Bosnia–Herzegovina, the rivers Strymon and Evros in Greece, and the river Morača in Montenegro [18]. Further records are available from the rivers Jadro, Žrnovnica, Sutorina, Bojana [32], Crna [33] Cetina and Ljuta [34]. However, most studies only report on the presence of European eels and limited quantifiable data are available.

Comparisons of densities of European eels among different rivers or studies is challenging for several reasons. First, there is significant geographical variation in the mean age and length of both males and females in Europe and North Africa [16]. Second, eel densities decline consistently with distance upstream of the tidal limit [35]. Furthermore, mortality rates, seasonal and annual variation, the availability of food, and water quality need to be taken into consideration [36], as well as other factors such as the virtual absence of unperturbed rivers. The lack of knowledge of the relationship between eel density and meso-habitat use makes it often impossible to predict the size of eel stocks in the river systems. In fact, density estimates are very often speculative and inaccurate, as the diversity of meso-habitats is not considered [37]. Although our data show a high standard deviation, the results are comparable to, or even higher than those found in some European rivers (e.g., the Imsa in Norway: 116 ind./ha [38]; the Oir in France: 300 ind./ha [39]; 181 UK streams: 300–1000 ind./ha [40]) but lower than others (e.g., the Rio Esva in Spain: 400–2000 ind./ha [41]; small tributaries of the Valaine in France: 430–20,800 [42]; Danish streams: 500–130,000 ind./ha [43]).

The results of habitat use are comparable to a smaller study conducted in the river Vjosa, where the highest numbers of European eels were caught at the shore of the main channel and, in one side, connected sidearms [24]. The highest densities were found in shallow habitats such as riffles and gravel banks. One exception was sand banks, which were represented with rather low densities, indicating a preference for coarser substrates. This pattern has also been reported in other studies [44,45]. It is noteworthy that some small individuals were caught using a kick-net (personal communication Gabriel Singer and Simon Vitecek) with a frame size of 25 × 25 cm that is used for benthic invertebrate sampling [46], indicating their presence in the interstitial of the loose substrate. The behavior of individuals and the quality and accessibility of habitats are major drivers of eel distribution. Homing and territorial behavior have also been observed in the limited movement of eels between the daytime and the night and their resting habitats [47], as well as by means of telemetry studies where displaced American eels (*Anguilla rostrata*) travelled over a distance of 10–100 km to return to their initial location [48]. Large individuals (>360 mm) were underrepresented in our study. This might be due to sampling limitations as eels progressively shift into deeper habitats as they grow [37,47] and our sampling was likely less efficient in deeper water (i.e., >2–3 m). The higher discharges that occurred during the study period may have influenced the results concerning the use of particular meso-habitats and lower detection due to reduced visibility. This is also demonstrated by the lack of catches in the middle of the main arm where the depth of the water reached 2–3 m during sampling; any fish that were present were likely not caught via EF. Therefore, total calculated abundances should be regarded as minimum estimates. Generally, there are limited standardized sampling techniques for large rivers because environmental conditions are often extremely variable and all sampling gears have their inherent biases [49]. Our approach most likely functioned well in shallower habitats across a number of meso-habitat types but was likely ineffective for eels in depths of > than 2 m, especially in the swifter flowing main channel. We currently do not know what eel densities in such habitats of the Vjosa may be, but considering our overall densities estimates are above average for most literature reports, our results underscore the quality and conservation importance of the river Vjosa for this critically endangered species.

Knowledge of the precise relationships between eel densities, sizes, and their habitats is crucial for predicting the size of eel stocks in river systems [37] and is urgently required [17]. Therefore, undisturbed rivers such as the Vjosa are perfect natural laboratories for further research. This knowledge and understanding of the habitat ecology of fish is a basic step in developing suitable management and conservation measures.

4.1. Threats of Hydropower Development

Recently, the entire Balkan area has come under strong pressure from the approximately 3000 planned hydropower projects, of which more than 1000 are located in protected areas such as national parks, nature reserves, and Natura 2000 sites. Concerning the Vjosa, the river itself is under threat from two already commissioned hydropower dams at its lower section (see Eco-Masterplan for Balkan rivers [22]). In addition, every large tributary of the Albanian catchment is scheduled to be damned, interrupted, or hydromorphologically altered.

Longitudinal connectivity is of paramount importance for long-distance migratory species that migrate between marine and freshwater environments [50,51]. Therefore, the complete blockage of upstream areas to migratory fish species has significant impact. Of the 1109 km river network in the Vjosa/Aoos river system, 1062 km are currently accessible to migratory fish. After the construction of the most recently proposed dams at Kalivac, 881 km will no longer be reachable from the sea and only 228 km (21.5%) will remain accessible. The river length of about 880 km of important foraging habitats would be lost by impounding the lower Vjosa. Assuming a similar density (2000 ind./km) for the upper sections, a rough estimation results in a total loss of 1.8 million individuals. However, densities are known to decline with increasing distance from the sea while mean sizes increase at the same time [35]. Therefore, a more realistic picture of the whole catchment is only possible with further detailed studies.

In principle, fish bypasses have the potential to mitigate upstream blockages to a certain extent. However, a review by Fjeldstad, et al. [52] highlighted that many of the existing fishways for upstream migration are not designed according to present knowledge. Eels in general, and glass eels in particular, demand specially designed (glass-) eel passages [53]. In the present case of the Kalivaç HPP, with a height difference of 37 m between the head and tail waters, its location in a canyon, and by applying European standards (e.g., BMLFUW [54], FAO [55]), this would result in one of the longest bypasses worldwide, with limited experience regarding its functionality. Downstream migration is as important as upstream migration, but is often neglected. In particular, the European eel is very sensitive in this regard because of its elongated body shape. Silver eels are much more vulnerable to turbine blade impingement compared to other species, resulting in reported cumulative mortalities of up to 100% after multiple turbine passages [56–60]. Estimations suggest that hydropower mortality accounts for more than 50% of anthropogenic mortality, where data for fishing and hydropower mortality was reported [61].

Furthermore, sections downstream of the reservoir are also seriously affected by disturbance to hydrological dynamics, riverbed incision due to trapped sediments, changed temperature regimes, food web alterations, and the loss of habitat [62]. Puijenbroek et al. [63] stated that currently, only two large European rivers are free flowing to the sea, the Torneälven and the Odra. The river Vjosa/Aoos is to be counted here as a third.

4.2. Conservation and Legal Aspects

In Albania, national legislation and the initiation of the National Network of Protected Areas constitute an important basis for the assessment of HPP projects and the protection of sites of high biodiversity value. Additional conservation requirements result from international conventions, particularly the integration process into the European Union. Albania is obliged to approximate its national legislation and assessment procedures concerning nature and biodiversity conservation with the legislation of the European Union, including the Water Framework Directive [64], Environmental Impact Assessment Directive [65], and European Habitats Directive [66]. Furthermore, the critical levels of the European eel stocks in Europe resulted in Regulation EC 1100/2007 [14], requiring

member states to reduce anthropogenic mortalities, by permitting the escape of at least 40% of the silver eel biomass to the sea. One key issue in meeting objectives that rely on the estimation of the pristine biomass of migrant eels is that historical data are missing, and estimates are mostly impossible. Additionally, the Convention on the Environmental Impact Assessment in a Transboundary Context [67] that was conducted in Espoo (Finland), on 25 February 1991 (signed by Albania signed in 1991), and amended by the 2nd amendment in 2004, requires the government to investigate and assess the environmental impacts of a project on a neighboring state if a project is likely to have a significant adverse transboundary environmental impact. Undoubtedly, this is the case for all dam projects on the Vjosa, as the blockage for migratory fish species will affect the stretches of the river and tributaries in Greece. Apart from this, it could be argued that any impact on the European eel, due to its panmictic character, would have a negative impact on the population worldwide and therefore affects all countries where it is native. In many Balkan countries, the application of environmental legislation has proved inadequate in several cases. Constraints arise from long-standing top-down planning traditions, inadequate planning of national environmental policies, poor administrative capacities, and heavy investment requirements, often combined with a lack of environmental awareness [68,69].

Extensive financial resources have been invested in restoration programs aimed at strengthening the remaining eel stocks. These include the enhancement of natural recruitment, either by installing eel ladders or by increasing the evacuation of glass eels from fisheries, habitat restoration, or restocking activities [8]. In an evaluation of the ‘European eel directive’ [14] the European Commission states that the status of the European eel remains ‘critical’. The stock is in decline, despite significant re-stocking efforts. The recruitment is at an all-time low and exploitation of the stock is currently unsustainable. Restocking seems more a short term emergency measure until greater natural migration in freshwater is possible, given its involved risks, such as disease introduction, mortality from poor handling, or its uncertain contribution to spawner escapement and subsequent recruitment [70]. Damming the last free-flowing rivers with high quality eel habitat will inevitably counteract all international efforts to reverse the trend of declining European eel populations, especially considering the fact that the eel is one large panmictic population and thus declines in one region affect the whole European eel population. Protecting natural freshwater areas with functioning habitat conditions might be a cost-effective measure to strengthen the species when integrated into a framework of freshwater biodiversity management [71,72].

Considering the current dramatic situation regarding European eel stocks and the extensive restoration efforts being made, it is apparent that the conservation of suitable freshwater habitats is one of the most significant issues in eel conservation. In this respect the near-natural river Vjosa/Aoos deserves the highest conservation status as the construction of hydropower dams would significantly degrade the high ecologic value of the entire river Vjosa from the delta to the areas upstream of the planned dam. Furthermore, potential violations of international and national law can be clearly identified.

Supplementary Materials: The following are available at <http://www.mdpi.com/2071-1050/12/20/8535/s1>, Figure S1: Pictures of European eel caught in the river Vjosa, Table S1: List of European eel (*A. anguilla*) records for the Vjosa/Aoos catchment.

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